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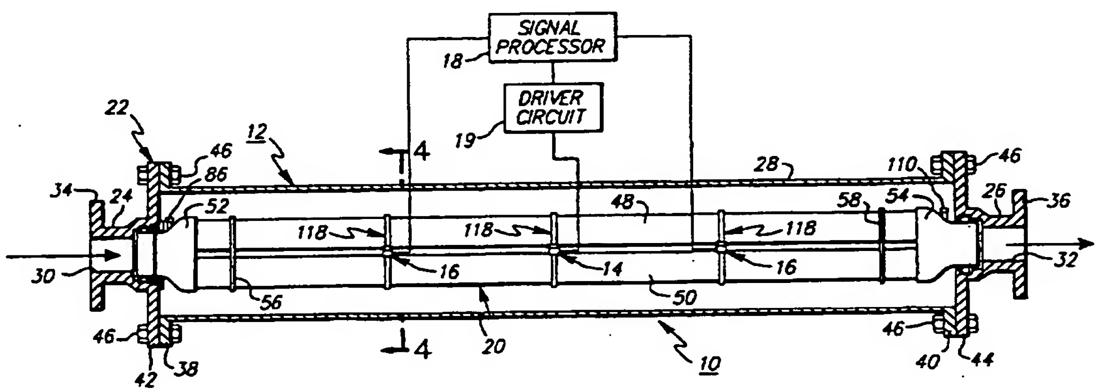

(57) Abstract

A conduit assembly for a Coriolis mass flow meter includes a conduit system through which a material under measurement flows. The conduit assembly is mounted to the support of the meter. Movement of the conduit system relative to the support is permitted, and prevents exposure of the conduit system to axial stress caused by temperature differences between the support and the conduit system. The conduit system includes two or four tubes through which the material travels in parallel.

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MASS FLOWMETER AND CONDUIT ASSEMBLY

BACKGROUND OF THE INVENTION

The present invention relates to meters, and, in particular, to "Coriolis meters," that is, meters that employ the "Coriolis" principle.

As is well known, a Coriolis meter measures the mass flow rate of a material that is directed through the conduits or tubes of a conduit system in the meter. Meters using the Coriolis principle can also measure the density and viscosity of the material. A Coriolis meter can, therefore, be configured to measure mass flow rate, density, and viscosity. Coriolis meters have become widely used primarily because they have no moving parts or any obstructions in the tubes, and they provide a relatively high degree of accuracy.

In the typical Coriolis meter, the conduit system includes one or more conduits, or tubes, through which the material flows. A driver oscillates or vibrates the tubes. Under a flow condition, the flow of the material through the tubes interacts with the oscillatory motion caused by the driver to produce a Coriolis force on the tubes, which alters the oscillatory motion of the tubes. This causes the oscillatory motion of the tubes at any two points along the tubes to be out of phase with each other. The degree of phase difference between the oscillatory motion at these two sensing points varies directly with flow rate, the phase difference being zero at a no flow condition. A Coriolis meter includes, therefore, sensors that produce sensor signals indicative of the oscillatory motion of the conduit system at two sensing locations on the conduit system, and a signal processing system that extracts from the sensor signals information related to the phase difference between the two sensor signals, and calculates the mass flow rate of the material. A housing protects the conduit system and prevents material, during a failure condition, from leaking from the meter.

Different conduit system configurations have been used in an attempt to improve the performance and accuracy of Coriolis meters. Systems using single and double (or dual) tube configurations have been used. In the case of dual systems,

parallel configurations have been used, in which the stream of material entering the meter is split fairly evenly into two streams, each of which flows through a different tube. Series configurations also have been used in dual tube conduit systems, in which the stream of material is not split, but flows first through one tube, and then the other. Different shaped tubes have been used as well. Straight, "s-shaped," "u-shaped," and oval shaped tubes are some of the many shapes that have been used.

The "dual straight" tube configuration provides a number of advantages. With straight tubes, the lateral dimension of the meter will be small relative to the lateral dimension of meters of similar capacity that use tubes that have bends. This can be quite an advantage, since lateral space in a piping system often is not readily available in an industrial environment. Straight tubes are also less expensive to manufacture than tubes that have bends, since the cost of forming the bends is eliminated. Straight tubes also eliminate the bends as a source of a drop in the pressure of the material flowing through the tube, thus reducing the energy needed to move the material through the meter. Furthermore, the bent sections of a bent tube are subject to a high degree of abrasion from any abrasive material that is flowing through the tubes. Also, the use of straight tubes permits use of a cylindrical housing.

Generally, the dual straight tubes are vibrated or oscillated in opposite directions by the driver. That is, the oscillatory motions of the two tubes are 180 degrees out of phase with each other. The tubes are fixed at their ends to a support. In some Coriolis meters, the housing itself serves as the support, while in others, the housing is nothing more than a "skin" that is mounted to the support. In any event, temperature differences between the support and the tubes, which occur from a number of causes, will cause axial stresses along the tubes, which change the vibration pattern of the tubes and cause measurement errors.

United States Patent No. 4,763,530 ("530") shows in Figures 7, 8, 9, and 10 meters employing tube configurations that are intended to compensate for the stresses caused by

temperature differences between the tubes and their supports. Figures 7 and 8 show a meter with flexible s-shaped tube sections 90, 92, 94 and 96, which act like springs that reduce the axial stresses on the straight tube sections 36 and 37 caused by the temperature differences. Similarly, the meter shown in Figures 9 and 10 employs helical shaped tubes 102 and 104 in an attempt to reduce the stress. The techniques disclosed in 530 can only reduce, but cannot eliminate, the axial stress and, therefore, the inaccuracies caused by temperature differences.

United States Patent No. 4,653,332 ("332") presents another approach to solving this problem, which involves the use of a pair of compensating tubes. The measuring tubes are connected to the compensating tubes, rather than the support, and the compensating tubes are mounted to the support. 332 states that the material from which the measuring tubes are made and the material from which the compensating tubes are made should have the same coefficient of thermal expansion, and, in fact, should be made of the same material. The theory underlying 332 is that by mounting the measuring tubes to the compensating tubes rather than the support, temperature differences occurring between the support and the measuring tubes will not impose axial stresses on the measuring tubes.

The meter described in 332 presents several problems. Generally, it would be unduly complicated, and costly and difficult to manufacture. The compensating tubes add to the effective length of the flow path, and the length of the tubes that convey the material under measurement. In essence, the material must flow through a distance that is three times the length of the meter. This increases the pressure drop of the meter, and adds material and labor costs. The compensating tubes also add to the overall width of the meter.

United States Patent No. 4,768,384 presents a substantially different approach. Rather than attempting to reduce or eliminate the axial stress, the meter disclosed in 384 attempts to compensate for it. Two temperature sensors are provided in the meter. One sensor senses the temperature of the tubes, and the second sensor senses the temperature of the support. The signal processing system uses any temperature

difference revealed by the sensor signals to adjust the mass flow rate calculated by the meter.

SUMMARY OF THE INVENTION

The present invention provides a conduit assembly for a meter through which material under measurement flows that includes a conduit system having a conduit through which the material flows, a support for the conduit system, and a coupling that substantially prevents temperature differences between the conduit system and the support from imposing axial stress on the conduit. Preferably, the conduit system defines a mounting section and the support defines a mounting passage, the mounting passage receiving the mounting section, and a fluid seal, the mounting section being free to slide within the mounting passage. The conduit can be straight and the conduit system can include any number of tubes, but preferably includes two or four straight tubes through which the material flows in parallel. Accordingly, the mounting section of the conduit system can slide within the mounting passage to substantially prevent temperature differences between the support and the conduit system from imposing axial stress on the conduit that would adversely affect measurement.

The present invention also provides a conduit assembly for a meter through which material under measurement flows that includes a conduit system through which the material flows that includes a mounting section, a support for the conduit system, and a mounting for mounting the conduit system to the support at the mounting section. The mounting permits movement of the mounting section relative to the support to substantially prevent temperature differences occurring between the conduit system and the support from imposing axial stress on the conduit system. The conduit system can include any number of tubes of virtually any shape, but preferably includes two or four straight tubes through which the material flows in parallel.

The present invention also provides a Coriolis mass flow meter that employs a conduit assembly provided by the present invention. The meter can include a first pressure sensor that determines the pressure within the conduit system at a first location and, also optionally, a second pressure sensor that determines the pressure within the conduit system at a

second location. If two pressure sensors are provided, the meter may be used for determining the viscosity of the material flowing through the conduit, as well as the mass flow rate and density of the material. Preferably, in the case of a meter having two straight tubes, the driver that oscillates or vibrates the tubes oscillates them in opposition, that is, 180 degrees out of phase with each other. The meter can include a pair of isolators, one isolator being secured to one end of each of the conduits to secure together those conduit ends, and the second isolator being secured to the remaining end of each of the conduits to secure together those remaining conduit ends. Preferably, the meter has a single driver and two sensors. The driver preferably oscillates the conduit system in the first mode, although higher modes of oscillation are anticipated. The meter mounting can include a seal that contacts and seals the mounting section, and the seal can be made of elastomeric material. The support can serve as a housing that completely envelopes the conduit system and functions as a pressure containment vessel for the meter. The meter can include a secondary support that is attached to the conduit system and that supports part of the driver or the sensors, or both, to reduce the load on the measuring tubes.

BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a side view, partially in section, of a Coriolis meter and conduit assembly provided by the present invention;

FIGURE 2 is a side sectional view of the mounting arrangement for the fixed end of the conduit system shown in **FIGURE 1**, with a pressure sensor added;

FIGURE 3 is a side sectional view of the mounting arrangement for the sliding end of the conduit system shown in **FIGURE 1**, with a pressure sensor added;

FIGURE 4 is a sectional view of the meter shown in **FIGURE 1** taken along the line 4-4;

FIGURE 5 shows the isolator used in the meter shown in **FIGURE 1**;

FIGURE 6 shows the coil and magnet assemblies for the meter shown in **FIGURE 1**, and a bracket assembly that is used to mount the driver and sensors to the conduits;

FIGURE 7 shows an alternate Coriolis meter and conduit assembly that has an alternate mounting arrangement for the driver and sensors;

FIGURE 8 shows the sensor and driver mounting arrangement for the conduit assembly shown in **FIGURE 7**;

FIGURE 9 is a side view, partially in section, of another embodiment of the present invention that employs four conduits;

FIGURE 10 is a sectional view of the meter shown in **FIGURE 9** taken along the line **10-10**;

FIGURE 11 is a sectional view showing the isolator used in the meter shown in **FIGURE 9**;

FIGURE 12 is a sectional view that shows the coil and magnet assemblies that serve as the driver and sensors for the meter shown in **FIGURE 9**, and a bracket that is used to mount the driver and sensors to the conduits;

FIGURE 13 is a top sectional view of the conduit assembly shown in **FIGURE 8** taken along the line **13-13**;

FIGURE 14 is an end view of the mounting strip or vane for the movable end of the secondary support shown in **FIGURE 13**;

FIGURE 15 is a side view of the mounting strip shown in **FIGURE 14**;

FIGURE 16 is a sectional view showing an alternate configuration and mounting arrangement for the coil and magnet assemblies of the meter shown in **FIGURE 1**; and

FIGURE 17 is an enlarged view of part of the apparatus shown in **FIGURE 16**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGURES 1 through 6 show a Coriolis meter 10 that can be constructed in accordance with the provisions of the present invention, and that can be used to measure the mass flow rate of a material flowing through meter 10. Meter 10 can also be configured, as is well known in the industry, to measure the density of the material. As is also known in the industry, with appropriate pressure sensors meter 10 can measure the viscosity of the material.

Meter 10 includes a conduit assembly 12 that includes a conduit or tube system 20 through which the material under measurement flows, a driver 14, a pair of motion sensors 16, a

driver circuit 19, and a signal processor 18. Driver circuit 19 can be any suitable driver circuit known in the Coriolis meter field that can be used to oscillate a driver. Signal processor 18 can be any suitable processor that can produce flow rate information from the motion signals produced by sensors 16. Driver 14 and sensors 16 can have any known suitable configuration. Driver 14 can be a coil and magnet assembly of known construction. The coil is excited by a periodic signal produced by driver circuit 19. The coil creates a time-varying electromagnetic field that causes the magnet and coil to reciprocate, which in turn causes the tubes of conduit system 20 to vibrate 180 degrees out of phase with each other. Similarly, each sensor 16 can be a coil and magnet assembly of known construction. Vibration of the conduits of conduit system 20 by driver 14 causes the magnets and coils of sensors 16 to reciprocate, which in turn causes the coils to produce a time varying electrical signal that signal processor 18 uses to calculate mass flow rate. Driver 14 and sensors 16 can be mounted to the tubes of conduit assembly 20 in any known fashion. Preferably, driver 14 is mounted to conduit system 20 midway between its ends, and a sensor 16 is mounted to conduit system 20 between driver 14 and each isolator located toward the ends of conduit system 20.

Typically, the material enters conduit assembly 12 through one end from the supply line that is conveying the material, passes through assembly 12, and exits meter 10 through the remaining end of assembly 12 to reenter the line. Driver 14 oscillates conduit system 20, and motion sensors 16 produce electrical signals that are related to the oscillatory motion of conduit system 20 at the points at which sensors 16 are mounted to conduit system 20. The phase difference between the signals created by sensors 16 is related to the rate of mass flow of the material through conduit system 20. The signals created by sensors 16 are sent to signal processor 18, which calculates the mass flow rate.

More particularly, conduit assembly 12 includes conduit system 20 and a support 22, which also functions as the housing and containment vessel for conduit system 20. Support 22 includes an inlet housing end 24, an outlet housing end 26,

and a housing 28. Inlet housing end 24 defines a flange 34 and an inlet passage 30, and is secured to the supply line with flange 34. Passage 30 is in fluid communication with the supply line, and permits the material to enter meter 10 from the supply line. Outlet housing end 26 defines a flange 36 and an outlet passage 32, and is secured to the line with flange 36. Passage 32 is in fluid communication with the line, and permits the material to flow from meter 10 back into the line.

Housing 28 is cylindrical and serves as the pressure containment vessel for meter 10. Housing 28 protects conduit system 20 and prevents material, during a failure condition, from leaking from meter 10. Housing 28 defines a pair of housing flanges 38 and 40. Housing 28 is secured at flange 38 to a flange 42 that is defined by end 24, and at flange 40 to a flange 44 that is defined by end 26 using bolting 46.

Conduit system 20 includes two conduits or tubes 48 and 50, which may be made of stainless steel, an inlet flow adaptor 52, an outlet flow adaptor 54, and a pair of isolators 56 and 58. Flow adaptor 52 is mounted to housing end 24, and flow adaptor 54 is mounted to housing end 26. Flow adaptor 52 is in fluid communication with passage 30, and splits the flow of material into two flow streams. Each tube 48 and 50 carries one of the flow streams through meter 10. Flow adaptor 54 is in fluid communication with passage 32, and recombines the streams flowing through tubes 48 and 50 into a single stream, which flows through passage 32 back into the line. As can be seen from **FIGURE** 4, each of tubes 48 and 50 has a circular cross section. Tubes 48 and 50 are mounted at their ends to adaptors 52 and 54 by, for example, brazing, and material can flow through adaptor 52 through tubes 48 and 50, exiting conduit system 20 through adaptor 54.

A driver 14 and a pair of motion sensors 16 are mounted to tubes 48 and 50. Driver 14 and sensors 16 can have any suitable configuration. Driver 14 can consist of a coil 160 and a magnet 162, which is partially inserted in coil 160, that are mounted to tubes 48 and 50 with a bracket assembly 118. When coil 160 is energized by a periodic electrical signal by driver circuit 19, magnet 162 and coil 160 are made to reciprocate. Tubes 48 and 50 are, accordingly, periodically

pulled toward and pushed away from each other by driver 14 when it is energized. Thus, driver 14 provides the vibration or oscillation of tubes 48 and 50 upon which the operation of a Coriolis meter relies.

Similarly, each sensor 16 includes a coil 160 and a magnet 162. The oscillation of tubes 48 and 50 causes magnet 162 and coil 160 to reciprocate. This periodic motion causes each coil 160 to produce a periodic electrical signal, which is transmitted to signal processor 18. Under a flow condition, due to the alteration of the oscillatory motion of tubes 48 and 50 caused by the interaction of the flow of material through tubes 48 and 50 and the vibration of tubes 48 and 50, the periodic signals produced by sensors 16 are out of phase with each other. Signal processor 18 calculates mass flow rate from this phase difference. Isolators 56 and 58 maintain the separation between tubes 48 and 50 at the locations at which they are secured to tubes 48 and 50, and improve the performance of meter 10.

FIGURES 2 and 3 show the couplings or mountings that are used to mount conduit system 20 to support 22. Generally, adaptor 54 is free to move axially with respect to housing end 26, while the position of adaptor 52 is fixed with respect to housing end 24. As a result, temperature differences between support 22 and conduit system 20 that otherwise would tend to cause ends 24 and 26 to exert an axial force on conduit system 20 and cause distortion of tubes 48 and 50, resulting in adverse variations in the vibration pattern of tubes 48 and 50, have no effect on measurement accuracy. Rather, the axial forces will simply cause adaptor 54 to slide within housing end 26. In essence, housing end 26 and flow adaptor 54 form a coupling or mounting that substantially prevents the imposition of axial stress on conduit system 20 that would otherwise be caused by a temperature difference between support 22 and conduit system 20.

Adaptor 52 defines a mounting section 64 that is used to mount conduit system 20 to housing end 24. Housing end 24 defines a mounting passage 66 that is sized to receive mounting section 64 of adaptor 52. Passage 66 defines an annular seat 68 that receives a seal 70 that is made of an elastomeric material. Seal 70 seals the space between mounting section 64 and passage 66 to ensure that material flowing through adaptor 52 does not

escape from conduit system 20. Mounting section 64 also defines an annular ring 72, and passage 66 defines an annular shoulder 74. An o-ring 76 is lodged between ring 72 and the wall of shoulder 74. A ring 78 is fastened to surface 80 of flange 42 with screws 82. A second o-ring 84 is lodged between ring 78 and ring 72. Seal 70, o-rings 76 and 84, rings 72 and 78, shoulder 74 and seat 68 cooperate to restrict axial movement of adaptor 52 within passage 66 and rotational movement of conduit system 20, and results in a mounting that has no metal-to-metal contact between the surfaces of adaptor 52 and housing end 24. Thus, the advantage is provided that seal 70 and o-rings 76 and 84 are the only means of support for adaptor 52.

A pressure sensor 86 can be mounted on adaptor 52, which would provide to processor 18 a signal that is related to the pressure within adaptor 52. Processor 18 would use the pressure signal to correct the mass flow rate and density measurements for pressure conditions existing within conduit system 20. Pressure sensor 86 can be any known suitable pressure sensor, and communicates with the interior of adaptor 52 through passage 88 that is formed in the wall of adaptor 52. Sensor 86 can be secured to adaptor 52 in any known fashion.

Adaptor 52 defines an inlet passage 90 and a pair of flow passages 92 and 94 that are separated by a divider 100. One end 96 of tube 48 is secured in any suitable fashion, such as brazing, within passage 92, and one end 98 of tube 50 is similarly secured within passage 94. Accordingly, material enters meter 10 through passage 30 from the supply line, and flows through passage 90 of adaptor 52. The material then is split into two streams by divider 100, which diverts one stream through passage 92 into tube 48, and the remaining stream through passage 94 into tube 50.

Adaptor 54 defines a mounting section 102 that is used to mount conduit system 20 to housing end 26. Housing end 26 defines a mounting passage 104 that is sized to receive mounting section 102 of adaptor 54. Passage 104 defines an annular seat 106 that receives a seal 108, which is made of an elastomeric material. Seal 108 seals the space between mounting section 102 and passage 104 to ensure that material flowing through adaptor 54 does not escape from conduit system 20. Seal 108 and seat

106 result in a mounting that has no metal-to-metal contact between the surfaces of adaptor 54 and housing end 26. Thus, the advantage is provided that seal 108 is the only means of support for adaptor 54.

Adaptor 54 is free to slide within passage 104. Accordingly, any temperature differences between support 22 and conduit system 20 will not cause housing ends 24 or 26 to exert axial stress on conduit system 20, but will simply result in axial movement of adaptor 54 within passage 104. The outer diameter of section 102, the inner diameter of passage 104, and the diameter and thickness of seal 108 must be chosen to permit section 102 to slide within passage 104, yet permit seal 108 to seal the space between section 102 and the surface of passage 104. Also, sufficient space must be provided between shoulder 105 of housing end 26 and the end of mounting section 102 to accommodate the anticipated effects of temperature differences occurring between support 22 and conduit system 20.

The mounting arrangement for conduit system 20 shown in **FIGURE** 3 substantially prevents temperature differences between support 22 and conduit system 20 from imposing axial stresses on conduit system 20. That is, conduit assembly 12 prevents the temperature differences from imposing stresses of a magnitude that would adversely affect measurement. The sizing of mounting section 102, passage 104, seal 108 and seat 106 should be chosen for each metering application to ensure that axial stresses that would be adverse to measurement in that application are avoided.

A pressure sensor 110 can be mounted on adaptor 54, which would provide processor 18 with a signal that is related to the pressure within adaptor 54. Processor 18 would use this second pressure signal to provide further correction of the mass flow rate and density measurements. Pressure sensor 110 can be any known suitable pressure sensor, and communicates with the interior of adaptor 54 through passage 112 that is formed in the wall of adaptor 54. Sensor 110 can be secured to adaptor 54 in any known fashion. The signals produced by sensors 86 and 110 can also be used to calculate the viscosity of the material flowing through meter 10.

FIGURE 5 shows isolator 56, which is identical to isolator 58, mounted in place on tubes 48 and 50. Isolator 56 defines an opening 116 that is sized to receive tube 48, and an opening 114 that is sized to receive tube 50. Isolators 56 and 58 improve the performance of meter 10.

FIGURE 6 shows the preferable configuration for sensors 16 and driver 14 and the preferable arrangement for mounting sensors 16 and driver 14 to tubes 48 and 50. In the arrangement shown in **FIGURE 6**, each sensor 16 and the driver 14 includes a pair of coil and magnet assemblies 158, each of which consists of a magnet 162 and a coil 160. Each of sensors 16 and driver 14 is mounted to tubes 48 and 50 with a two piece mounting bracket assembly 118. In the case of driver 14, each coil 160 is driven by the same oscillatory electrical signal produced by driver circuit 19, and, therefore, coil and magnet assemblies 158 of driver 14 oscillate in unison with each other. Bracket assembly 118 transmits the motion of the oscillating coil and magnet assemblies 158 to tubes 48 and 50 to vibrate tubes 48 and 50. Likewise, the coil and magnet assemblies 158 of each sensor 16 are moved in unison by the vibrating tubes 48 and 50 and brackets 118 to produce identical oscillatory motion signals, which are combined at each sensor 16 to obtain a single periodic sensor signal. Thus, two sensor signals are produced by meter 10.

Mounting brackets 118 are used to mount driver 14 and sensors 16 to tubes 48 and 50. Three brackets 118 are, therefore, employed, one for driver 14 and two for sensors 16. All three brackets 118 are identical to each other. Bracket 118 defines a magnet holder 120 and a coil holder 122. Magnet holder 120 defines an opening 124 that receives tube 48. Magnet holder 120 also defines a pair of shoulders 126 that act as the mounting seats for magnets 162 of coil and magnet assemblies 158. Magnets 162 can be mounted to shoulders 126 in any desired fashion. Similarly, coil holder 122 defines an opening 128 that receives tube 50, and a pair of shoulders 130 that act as the mounting seats for coils 160 of coil and magnet assemblies 158.

FIGURES 7, 8 and 13 through 15 show an alternate driver 169 and sensors 167, and alternate mounting apparatus for driver 169 and sensors 167, which employ the same two piece

mounting bracket assemblies 118 shown in **FIGURE 6**. Each of the sensors 167 and driver 169 consists of a pair of coil and magnet assemblies 164, each of which in turn consists of a pair of coils 166 and a magnet 168. A coil 166 is mounted in any desired manner to each shoulder 126 and 130 of holders 120 and 122 of bracket assembly 118. Each end of a magnet 168 is located in a coil 166, and is mounted to a support rod 170 with an extension 172. As can be seen from **FIGURE 7**, supports 170 extend along the entire length of tubes 48 and 50, and are secured at their ends to adaptors 52 and 54. The position of one end 412 of rod 170 relative to conduit system 20 is fixed, while the remaining end 400 is movable. The ability of end 400 to move with respect to conduit system 20 substantially prevents temperature differences occurring between rods 170 and adaptors 52 or 54 from imposing axial stresses on conduit system 20.

Movable end 400 of each rod 170 is secured to adaptor 54 with a thin flexible metal strip 402. As shown in **FIGURES 13 through 15**, metal strip 402 defines a pair of seats 404 and a flexible mount 406. Strip 402 is secured to adaptor 54 with screws 408, which are threaded through seats 404. A screw 410 is used to secure mount 406 to end 400 of rod 170. The fixed end 412 of each rod 170 is mounted to adaptor 52 with a conventional bracket 414. Bracket 414 defines mounts 416 and 418. Mount 418 is secured to end 412 of rod 170 with a screw 420, and mount 416 is secured to flow adaptor 52 with screws 422. Preferably, each of members 404 and 406 is between .005 and .015 in. in thickness. Therefore, any temperature difference occurring between rod 170 and adaptors 52 or 54 will cause flexible mount 406 of strip 402 to flex, and substantially prevent axial stresses from being imposed on conduit system 20.

Alternately, end 400 of each rod 170 may be secured to adaptor 54 in the same manner in which flow adaptor 54 is mounted to housing end 26.

In an alternate configuration for the assembly shown in **FIGURE 7**, coils 166, rather than magnets 168, are secured to supports 170. In this arrangement, for each sensor and the driver, a magnet 168 is secured to each shoulder 126 and 130 of each bracket assembly 118, and a coil 166 is located around each pair of confronting ends of magnets 168, and mounted to rod 170

with an extension 172.

FIGURES 9 through 12 show an alternate conduit assembly 300 that is provided by the present invention. Conduit assembly 300 provides greater flow capacity for a given housing diameter. Conduit assembly 300 includes a conduit system 303 that includes four conduits 304, 306, 308, and 310. A driver 344 and a pair of sensors 346 are mounted to the conduits with mounting bracket assemblies 301. A pair of isolators 320 and 321 are mounted to the conduits. Each of driver 344 and sensors 346 includes a pair of coil and magnet assemblies 342. Like conduit assembly 10, conduit assembly 300 has a support 309, that includes a pair of housing ends 316 and 318, and a housing 313. Adaptor 314 is mounted for sliding movement with respect to housing end 318 in the same manner as movable adaptor 54 is mounted to housing end 26 of conduit system 12. Accordingly, conduit assembly 300 substantially prevents temperature differences between conduit system 303 and support 309 from imposing axial stress on conduit system 303.

Conduit assembly 300 is identical to conduit assembly 12, with the exceptions that conduit assembly 300 has four measuring tubes 304, 306, 308, and 310 instead of two, and, to accommodate the four measuring tubes:

1) Flow adaptors 312 and 314 are larger than adaptors 52 and 54, and define four, rather than two, flow passages;
2) Housing 313 and housing ends 316 and 318 are larger than housing 28 and housing ends 24 and 26;
3) Isolators 320 and 321 are larger than isolators 56 and 58, and define four openings 322, 324, 326, and 328, instead of two, to receive tubes 304, 306, 308, and 310; and,
4) Mounting bracket assemblies 301 are larger than bracket assemblies 118, and define four openings 334, 336, 338, and 340 to receive tubes 304, 306, 308, and 310.

Mounting bracket assemblies 301 of conduit assembly 300 constrain a pair of tubes 304 and 306 to move as a unit 305,

and a pair of tubes 308 and 310 to move as a unit 307. Accordingly, the coil and magnet assemblies 342 of driver 344 cause tubes 304 and 306 to vibrate as a unit 305, and tubes 308 and 310 to vibrate as a unit 307, as though each unit 305 and 307 were a single tube. Similarly, the coil and magnet assemblies 342 of each sensor 346 produce motion signals for the tube unit 305 and the tube unit 307, as though each unit 305 and 307 were a single tube.

FIGURES 16 and 17 show an alternate configuration and mounting arrangement for the magnet and coil assemblies for the driver and sensors of meter 10 shown in **FIGURE 1**. One magnet and coil assembly 500 is used for each driver and sensor of meter 10. Three magnet and coil assemblies 500 in total would be used for meter 10. Each magnet and coil assembly 500 includes a coil element 502 and a magnet element 504. As can be seen in **FIGURE 17**, coil element 502 includes a coil 506 and a core 508. Core 508 defines an annular recess 514 in which coil 506 is wound. Core 508 also defines a tube mounting end 528, at which core 508 is mounted to tube 48. End 528 defines a curved seat 530, the curve of which matches the curve of conduit 48, and a chamfer 516. Core 508 is secured to conduit 48 at end 528 and seat 530 by applying a suitable adhesive 510 to seat 530 and chamfer 516, and engaging seat 530 with tube 48.

Core 508 also defines a cylindrical passage 512 that receives the magnet 520 of magnet element 504. Magnet 520 is secured to a magnet adaptor 532. Magnet adaptor 532 is made from a suitable powdered metal, and is sized to ensure that magnet 520 extends sufficiently into passage 512 of coil element 502. Magnet adaptor 532 defines a tube mounting end 522, at which mounting adaptor 532 is mounted to tube 50. End 522 defines a curved seat 536, the curvature of which matches the curvature of conduit 50, and a chamfer 540. Magnet element 504 is secured to conduit 50 by applying suitable adhesive 524 to seat 536 and chamfer 540 and engaging seat 536 with tube 50. Adhesives 510 and 524 can be any suitable adhesive, such as an ultraviolet curing adhesive or an epoxy.

The magnet and coil assembly 500 that is used as a driver is excited in the usual manner. Similarly, the magnet and coil assemblies that serve as the sensors produce signals

that are processed in the usual manner. Due to the fact that magnet and coil assemblies 500 are located in the plane defined by conduits 48 and 50, they should operate more effectively than magnet and coil assemblies 158 shown in **FIGURE 6** when conduits 48 and 50 are subjected to torsional forces.

INDUSTRIAL APPLICABILITY

The way in which the present invention is capable of exploitation in industry and the way in which it can be made and used is deemed to be obvious from the description or nature of the invention.

What is claimed is:

1. A conduit assembly for a meter through which material under measurement flows comprising:

a conduit system including a conduit through which the material flows;

a support for said conduit system; and

a coupling between said conduit system and said support that substantially prevents temperature differences between said conduit system and said support from imposing axial stress on said conduit.

2. The conduit assembly recited by claim 1 wherein said conduit system and said support together define said coupling.

3. The conduit assembly recited by claim 2 wherein said conduit system defines a conduit mounting section at which said conduit system is mounted to said support, and said support defines a mounting passage, said mounting passage receiving said mounting section, and a fluid seal located between said mounting section and said mounting passage, said mounting section being free to slide within said mounting passage through a predetermined distance.

4. The conduit assembly recited by claim 1 wherein said conduit is straight.

5. The conduit assembly recited by claim 4 wherein said conduit system includes two said straight conduits.

6. The conduit assembly recited by claim 5 wherein the material flows through said conduits in parallel.

7. The conduit assembly recited by claim 1 wherein said conduit system includes four said straight conduits.

8. The conduit assembly recited by claim 7 wherein the material flows through said conduits in parallel.

9. A conduit assembly for a meter through which material under measurement flows comprising:

a conduit system through which the material flows, said conduit system including a mounting section;

a support for said conduit system; and

a mounting for mounting said conduit system to said support at said mounting section;

said mounting permitting movement of said

mounting section relative to said support.

10. The conduit assembly recited by claim 9 wherein said conduit system includes one straight tube.

11. The conduit assembly recited by claim 10 wherein said conduit system includes two straight conduits through which the material flows in parallel.

12. The conduit assembly recited by claim 11 wherein said conduit system includes four straight conduits through which the material flows in parallel.

13. A conduit assembly for a meter through which material under measurement flows comprising:

a conduit system including a conduit through which the material flows;

a support for said conduit system; and

means for substantially preventing temperature differences between said conduit system and said support from imposing axial stress on said conduit system.

14. The conduit assembly recited by claim 13 wherein said conduit system includes two said conduits through which the material flows in parallel.

15. The conduit assembly recited by claim 13 wherein said conduit system includes four said conduits through which the material flows in parallel.

16. A mass flow meter comprising:

a conduit system including a conduit through which the material flows;

a support for said conduit system;

a coupling that substantially prevents temperature differences occurring between said conduit system and said support from imposing axial stress on said conduit;

a driver used to oscillate said conduit system;

a sensor assembly that detects the motion of said conduit system while it is being oscillated by said driver and produces sensor signals that are related to the oscillatory motion of said conduit system; and

a signal processing system that derives from said sensor signals information pertaining to the mass flow rate of the material through said meter.

17. The meter recited by claim 16 wherein said

conduit system and said support together define said coupling.

18. The meter recited by claim 17 wherein said conduit system defines a conduit mounting section at which said conduit system is mounted to said support, and said support defines a mounting passage, said mounting passage receiving said mounting section, and a fluid seal located between said mounting section and said mounting passage, said mounting section being free to slide within said mounting passage through a predetermined distance.

19. The meter recited by claim 16 wherein said conduit is straight.

20. The meter recited by claim 19 wherein said conduit system includes two said straight conduits.

21. The meter recited by claim 20 wherein the material flows through said conduits in parallel.

22. The meter recited by claim 19 wherein said conduit system includes four said straight conduits.

23. The meter recited by claim 22 wherein the material flows through said conduits in parallel.

24. The meter recited by claim 16 further comprising a first pressure sensor that determines the pressure within said conduit system at a first location.

25. The meter recited by claim 24 further comprising a second pressure sensor that determines the pressure within said conduit system at a second location, said first and second sensors being useful for determining the viscosity of the material flowing through said conduit.

26. A meter for measuring the mass flow rate of a material comprising:

a conduit system through which the material flows, said conduit system including a mounting section;

a support for said conduit system;

a mounting for mounting said conduit system to said support at said mounting section;

said mounting permitting movement of said mounting section relative to said support;

a driver used to oscillate said conduit system;

a sensor that detects the motion of said conduit system while it is being oscillated by said driver assembly, and

produces sensor signals that are related to the motion of said conduit system sensed by said sensor; and

a signal processing system that derives from said sensor signals information pertaining to the mass flow rate of the material through said meter.

27. The meter recited by claim 26 wherein said conduit system includes a straight conduit through which the material flows.

28. The meter recited by claim 27 wherein said conduit system includes two said straight conduits through which the material flows.

29. The meter recited by claim 28 wherein said driver oscillates said conduits 180 degrees out of phase with each other.

30. The meter recited by claim 29 further comprising a pair of isolators, one said isolator being secured to one end of each of said conduits to secure together said conduit ends, and the second said isolator being secured to the remaining end of each of said conduits to secure together said remaining conduit ends.

31. The meter recited by claim 30 further comprising a second said driver.

32. The meter recited by claim 29 wherein said sensor includes two coil and magnet assemblies.

33. The meter recited by claim 29 wherein said sensor includes more than two said coil and magnet assemblies.

34. The meter recited by claim 26 wherein said driver includes a single coil and magnet assembly and oscillates said conduit system in the first mode.

35. The meter recited by claim 26 wherein said driver includes more than one coil and magnet assembly and oscillates said conduit system in a mode higher than the first mode.

36. The meter recited by claim 26 wherein said mounting includes a seal that contacts and seals the mounting section.

37. The meter recited by claim 36 wherein said seal is made of elastomeric material.

38. The meter recited by claim 26 wherein said support defines a housing for the said meter that functions as a

containment vessel.

39. The meter recited by claim 27 wherein said conduit system includes four said straight conduits.

40. The meter recited by claim 39 wherein said driver oscillates a first pair of said conduits 180 degrees out of phase with the oscillation of a second pair of said conduits.

41. The meter recited by claim 40 wherein the material flows through said conduits in parallel.

42. The meter recited by claim 26 wherein said conduit assembly further comprises a secondary support.

43. The meter recited by claim 42 wherein part of said driver is supported by said secondary support.

44. The meter recited by claim 42 wherein part of said sensor is supported by said secondary support.

45. The meter recited by claim 42 wherein part of said driver and part of said sensor are supported by said secondary support.

46. The meter recited by claim 29 wherein said sensor includes two coil and magnet assemblies.

47. The meter recited by claim 46 wherein said driver includes a coil and a magnet.

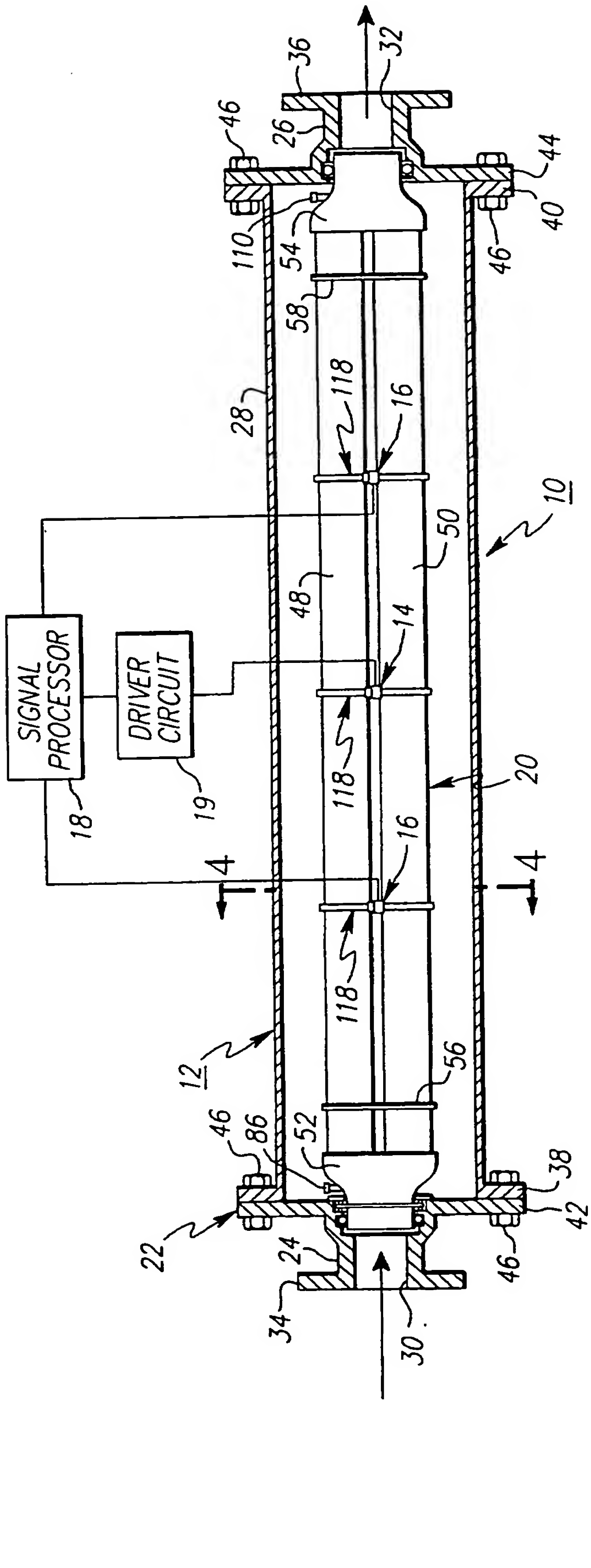

FIG. 1

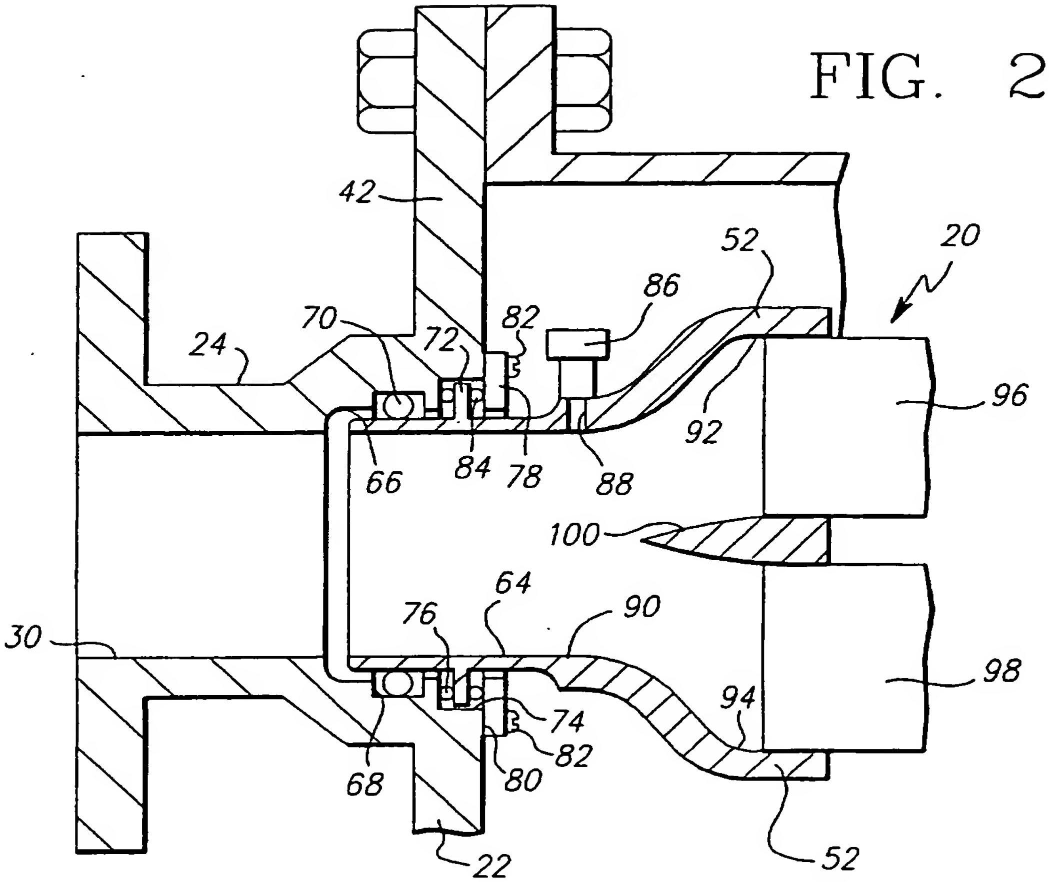
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FIG. 2

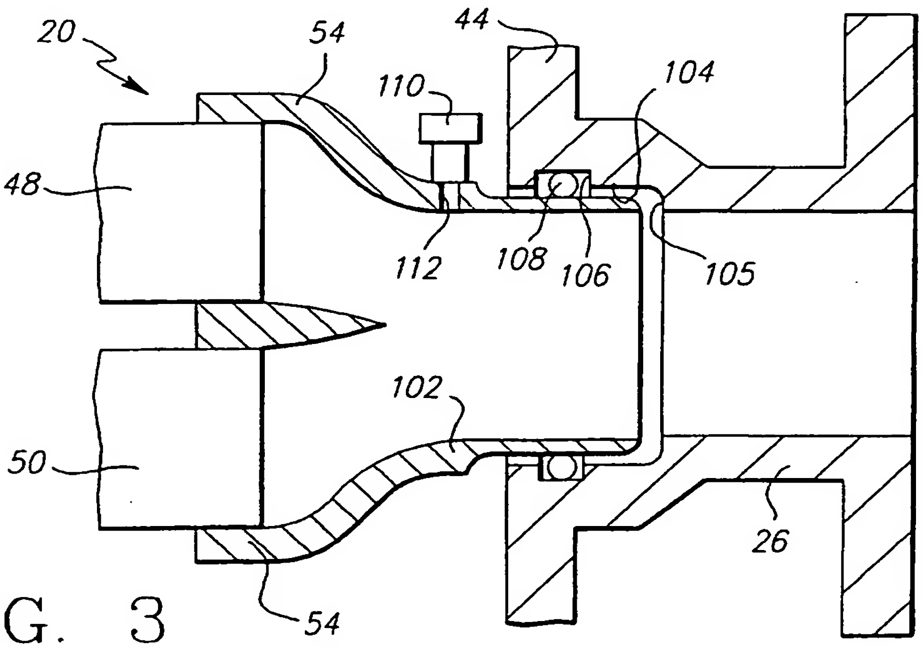
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FIG. 3

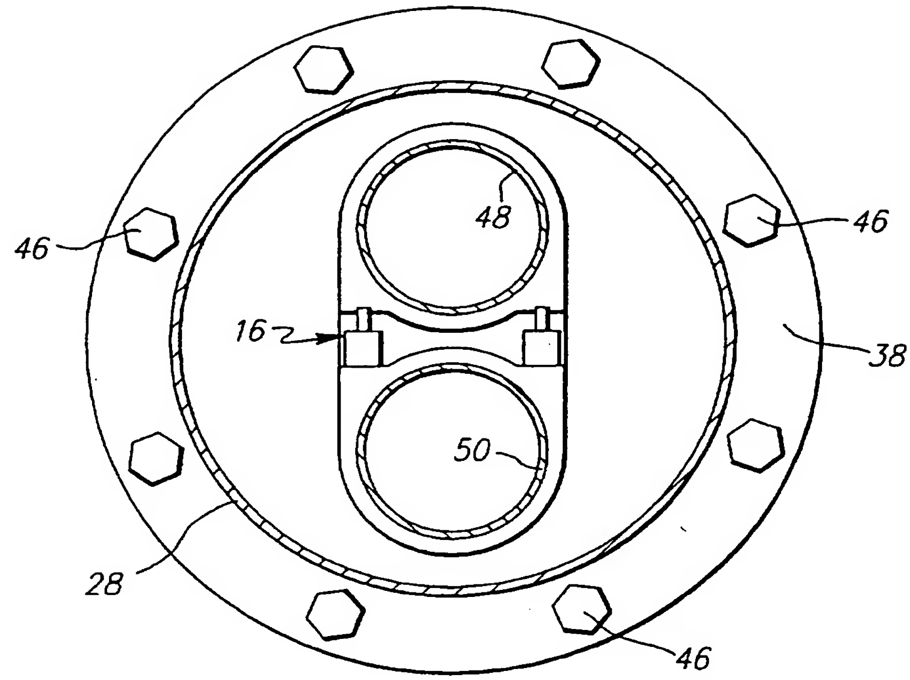

FIG. 4

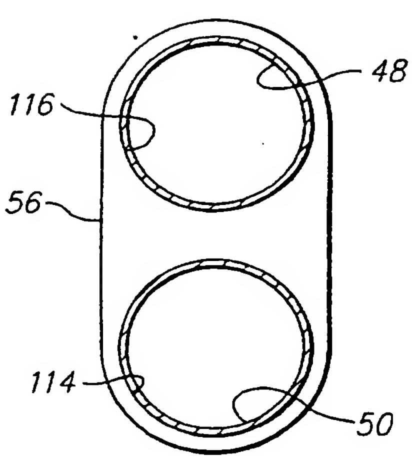

FIG. 5

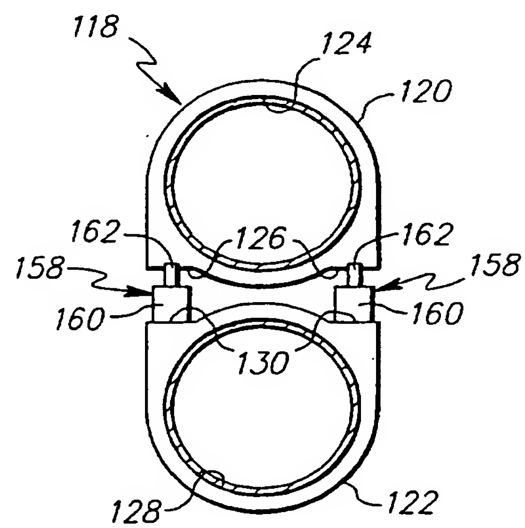

FIG. 6

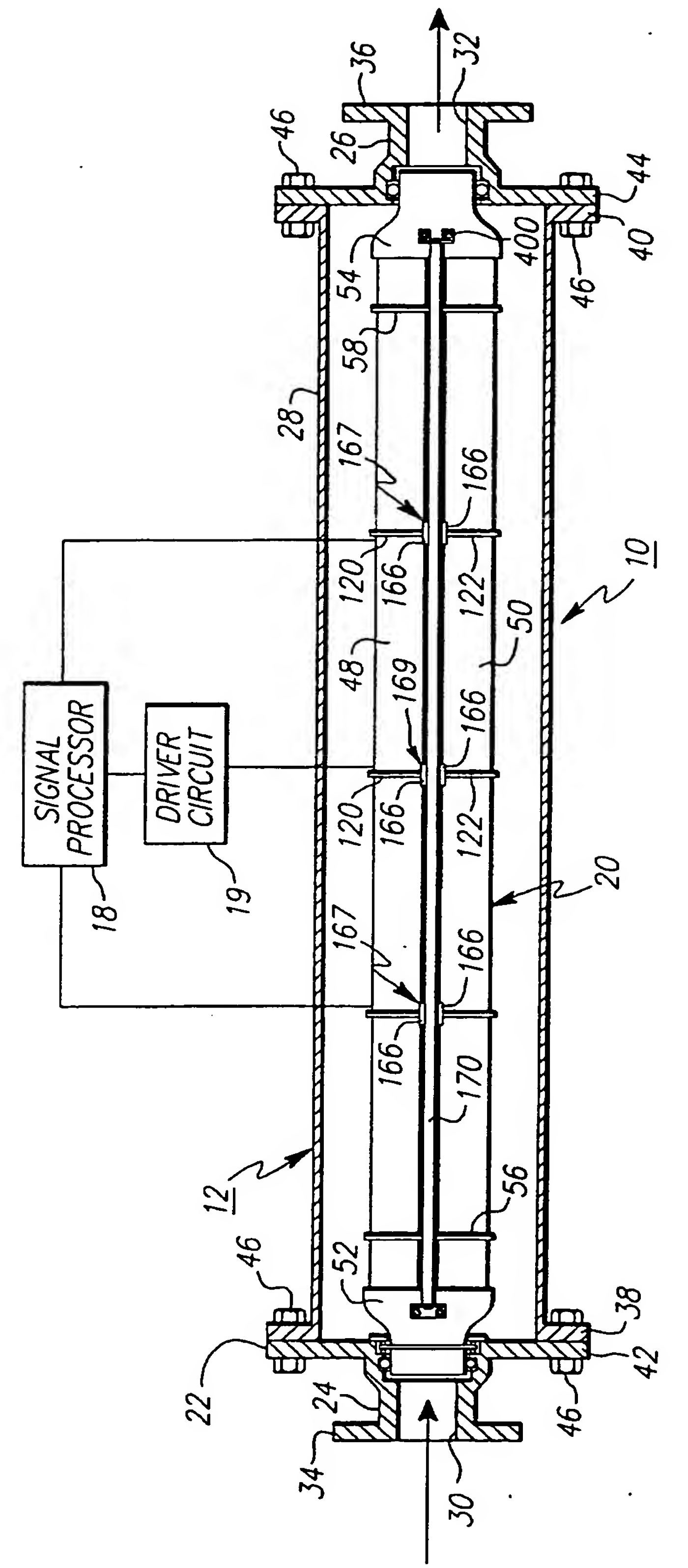
SIGNAL PROCESSOR
DRIVER CIRCUIT
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FIG. 7

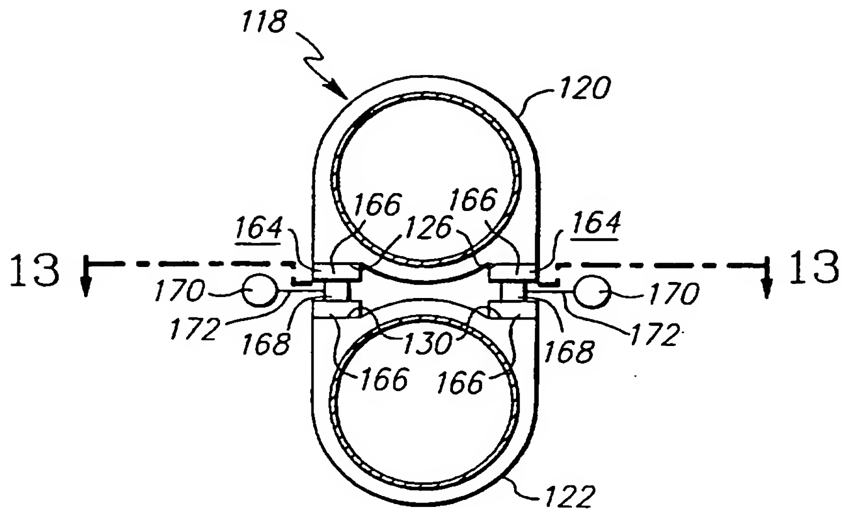
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FIG. 8

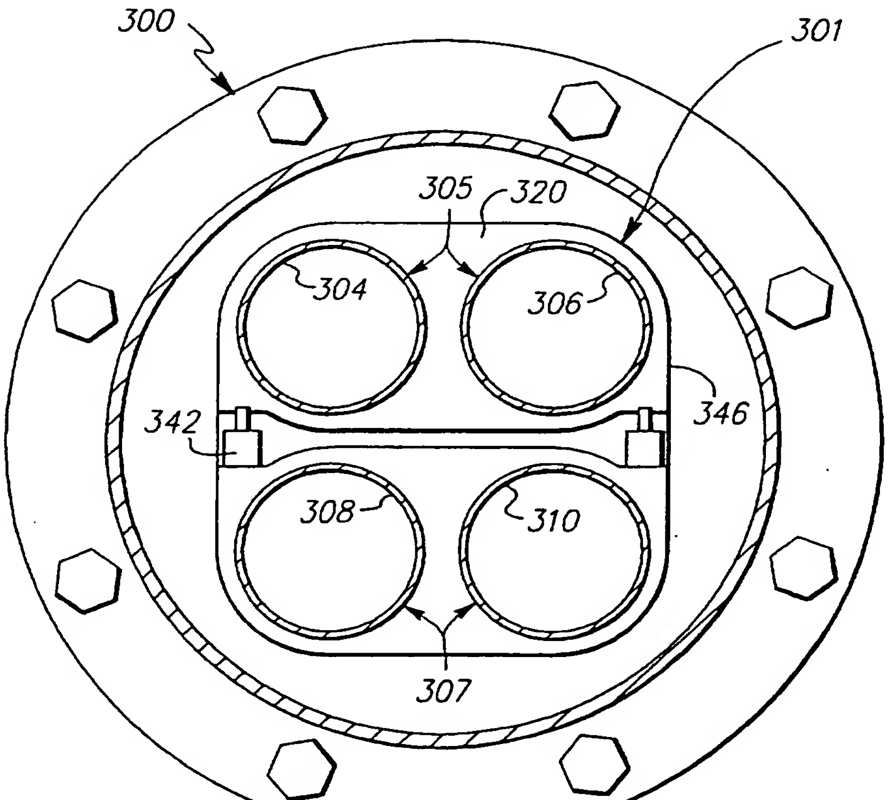
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FIG. 10

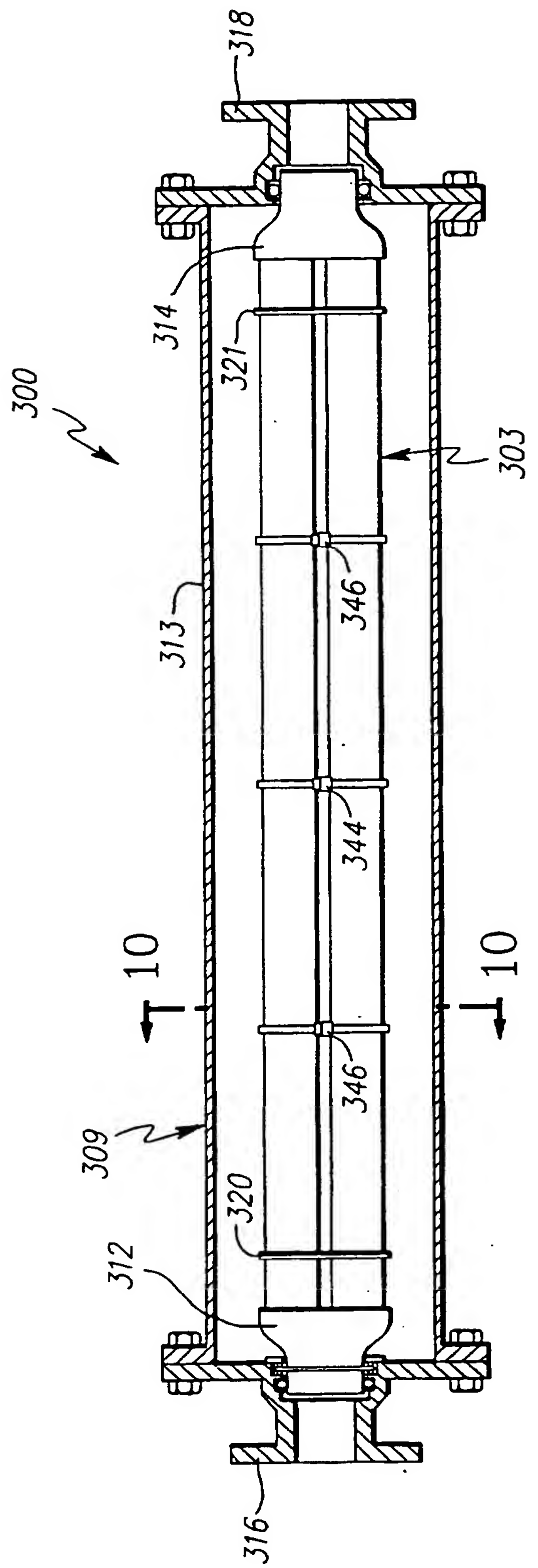

FIG. 9

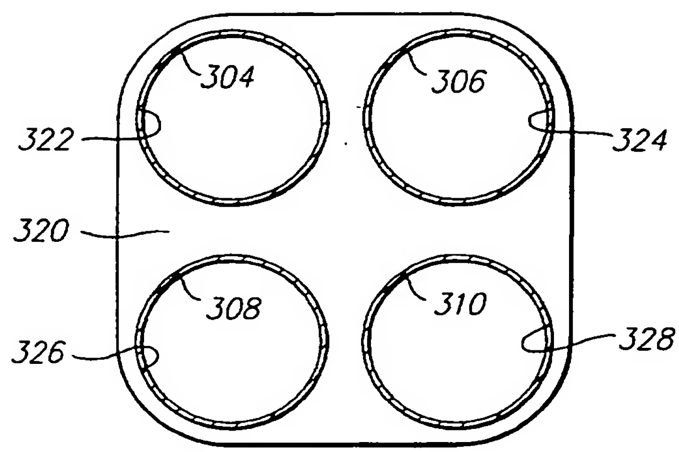
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FIG. 11

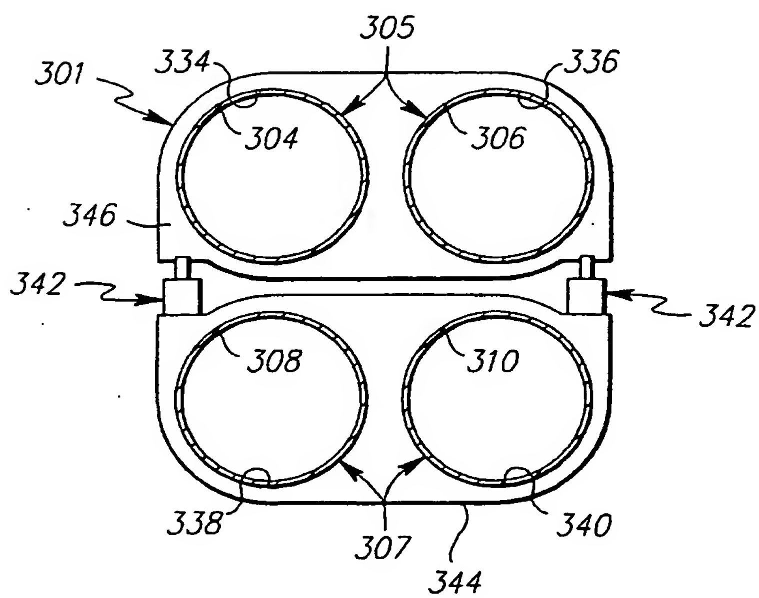
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FIG. 12

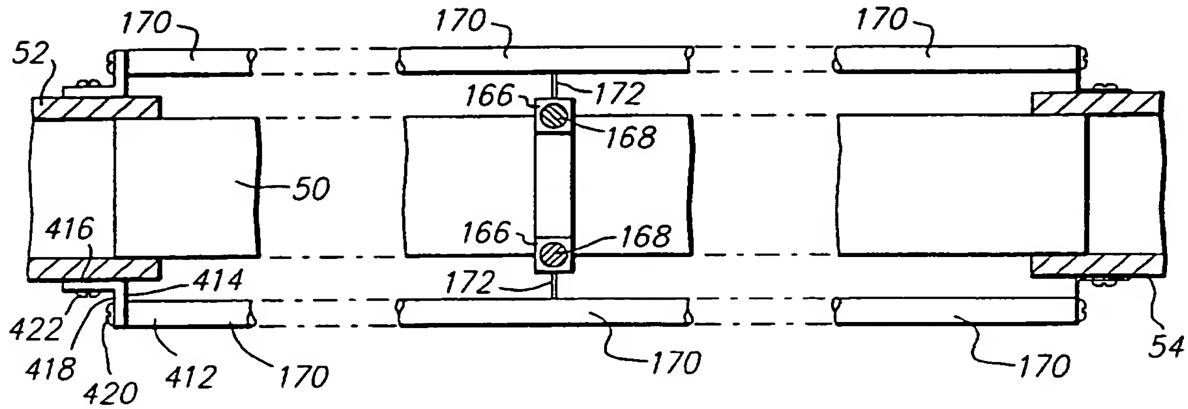

FIG. 13

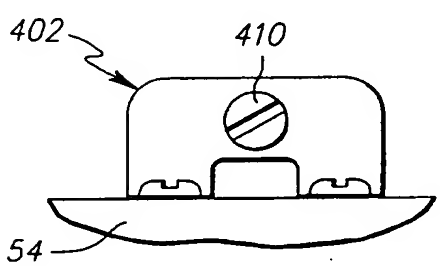

FIG. 14

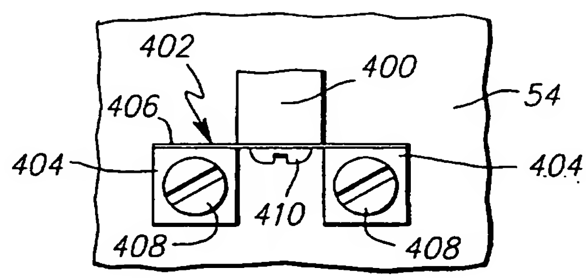

FIG. 15

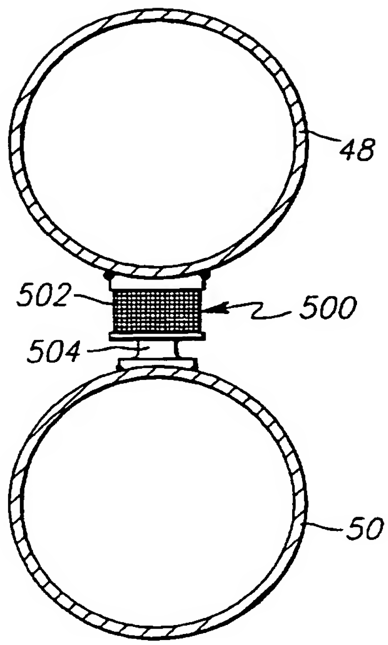
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FIG. 16

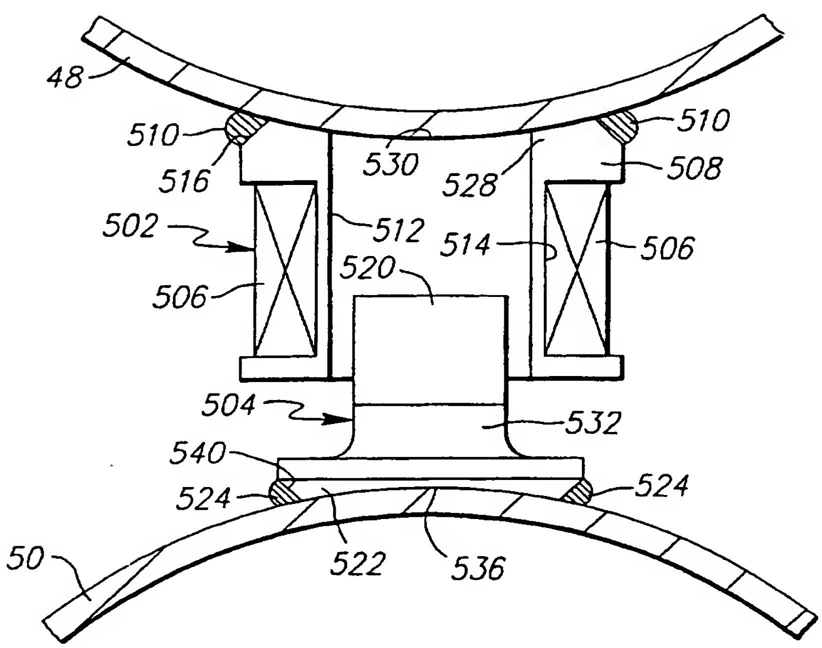
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FIG. 17